Quantification of Lagrangian and Small Scale Processes

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LONG-TERM GOALS

The long term goal of our research is to quantify the dynamics of submesocale processes and their interactions with motions at larger scales. In particular, we are interested in using high resolution disparate (HRD) data sets to develop dynamically consistent nowcasts of a flow field, and in using HRD surface observations to infer subsurface flow conditions. We also recently completed the development of a method for using a particle-in-cell (PIC) model to parameterize submesoscale processes in regional scale models.

OBJECTIVES

Our research has two components, each with specific objectives:

Blending HRD data with numerical models - Our objective here is to develop dynamically consistent nowcasts to support Rapid Environmental Assessment (REA), by combining the information in disparate data sets like HF radar, Lagrangian observations, passive remote sensing and ADCP data with open boundary flow information from a numerical model. Information from this type of nowcast may then be used to infer some features of the subsurface flow field. Nowcast results may also be assimilated into a numerical model.

PIC ocean model. Our objective here, completed during this performance period, was to develop a PIC model for two active layers, capable of resolving the location and evolution of fronts in coastal and estuarine regimes. The PIC model results can be used to parameterize these features in regional scale models. The model was developed to run on massively parallel processor (MPP) architectures.

APPROACH

Blending HRD data with numerical models - The approach uses normal mode analysis (NMA), a spectral technique in which the data are projected onto numerically generated basis functions. This method is a generalization of a spectral method first described by Rao and Schwab (1981) in an analysis of currents in Lake Ontario. It is described by Eremeev *et al*. (1992a), and applied to a variety of oceanographic data by Eremeev *et al.* (1992b), Eremeev *et al*. (1995a,b), Lipphardt *et al*. (1997, and

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Cho *et al.* (1998). This approach was selected because it has a number of attributes appropriate for REA. It is spectral and thus applicable to disparate data; it is readily adapted to arbitrarily shaped domains and thus is ideal for REA scenarios; the spatial basis set can be calculated to arbitrary accuracy independent of the data which is appealing for high resolution data; boundary information from numerical models is easily incorporated with observations which simplifies blending of observations and model information; and the rendered velocity field is three-dimensionally incompressible.

PIC ocean model - The PIC model solves the Euler equations using a hybrid approach. The acceleration and Coriolis terms are solved at particles while the pressure gradient terms are solved on a grid. Dynamic coupling between the layers occurs through the pressure terms. This method is capable of faithfully resolving fronts while retaining primitive equation dynamics.

WORK COMPLETED

Blending HRD data with numerical models - We have developed the numerical code, using a sparse matrix method, to calculate the NMA basis functions for any domain geometry, including geometries with interior islands. The NMA method has been applied to HF radar data from Monterey Bay, supplied by Jeff Paduan. This application allowed us to explore the use of NMA for both spatial and temporal filtering, and to test the a sensitivity of these nowcasts to subsampling of HRD observations. We have also developed methods for coping with HRD data that contains spatial gaps.

PIC ocean model - We recently completed work using the first ever multilayered PIC model. The problem considered was a shallow lens over a deep layer which outcrops around the lens. During the past year, two problems were investigated. The first problem was a systematic study of the stability of an isolated surface lens subjected to shear in the lower layer. The second problem was the adjustment of both layers to unbalanced initial conditions.

RESULTS

Blending HRD data with numerical models - We have developed an objective technique for both spatial and temporal filtering of HRD data as part of the nowcast. Time series analysis of the time-dependent mode amplitudes allows the global spectral properties of the data to be studied. NMA also permits the calculation of velocity gradient fields to the same order of accuracy as the velocity field, so that quantities like enstrophy can be studied. We now understand the sensitivity of the NMA approach to subsampling of the available HRD observations, and we have developed a technique for supplementing the observations with model velocities in regions where observations may be missing. Lewis *et al.* (1998) reported that the HF radar observations contained significant noise in the divergence field, making it difficult to assimilate into a numerical model. Monterey Bay surface velocity nowcasts using NMA have coherent vorticity and divergence distributions, so that the NMA approach may be a useful way to filter these observations before they are assimilated into a model.

PIC ocean model - The model ansatz is described in Kirwan *et al.* (1997). There, an assessment of the PIC approach was made by comparing model generated flow invariants for the reduced gravity case with analytic results first obtained by Ball (1963, 1965). Holdzkom (1998) extended those results by including both prescribed and dynamically adjusted flows in the lower layer.

IMPACT/APPLICATIONS

Blending HRD data with numerical models - The NMA method we have developed is an important tool for blending HRD data in a dynamically consistent way. It is applicable to any data and any grid at any resolution, and it incorporates traditional boundary conditions. Thus, it is particularly well-suited to REA applications.

PIC ocean model - PIC models should be useful in studying the evolution of submesoscale features such as fronts that cannot be resolved in traditional models. Moreover, since PIC models calculate particle trajectories as part of the solution algorithm, they will be important in Lagrangian transport studies.

TRANSITIONS

A Ph.D. student here, LCDR W. Schulz, has been working with the Naval Research Lab's Ocean Dynamics and Prediction Branch (Stennis Space Center - NRLSSC) in blending both Lagrangian drifter and current meter data with their model of the Louisiana-Texas shelf area in the Gulf of Mexico. The NRLSSC 1/16 degree model of the Gulf of Mexico is being made available for this study. This will be LCDR Schulz's dissertation work.

RELATED PROJECTS

ONR has also provided us with DRI support to study the dynamical systems characteristics of ocean flows as part of the project titled "Enhanced Ocean Predictability Through Optimal Observing Strategies**.**" As part of this work, we will use the NMA method to calculate Lagrangian trajectories to be analyzed by our collaborators using traditional dynamical systems tools. The Gulf of Mexico will likely be the test domain for the early part of this work.

As part of our ONR sponsored work we have been collaborating with scientists from the Naval Post Graduate School, the SACLANT Undersea Research Centre (La Spezia, Italy), the University of Colorado, and Ocean Physics Research and Development to continue analysis of HF radar data and to assimilate this data into predictive models.

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